High pressure single-crystal elasticity of a mixed-composition garnet

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Garnet is a major component of the earth’s upper mantle, transition zone, and uppermost lower mantle, potentially exceeded only by olivine and its high-pressure polymorphs over these regions. In order to properly determine the chemical composition and mineralogy of the upper mantle, we must have a detailed understanding of the effect of pressure, temperature, and composition on the elasticity of garnet. Garnet in the mantle is represented by a solid solution of Mg, Fe, and Ca, forming pyrope (py), almandine (alm), and grossular (grs), with Si gradually substituting for Al at high pressure. The effects of these compositional variables on the elasticity of garnet is often considered to be linear. Here we present sound velocity measurements via Brillouin spectroscopy on a natural, eclogitic mixed garnet of composition Py81Grs11Alm8. Single-crystal elastic moduli were determined, up to 14 GPa. Values for the elastic moduli at ambient conditions are (in units of GPa): $K_0 = 160.6(3)$, $G_0 = 89.4(1)$, $C_{11} = 278.7(10)$, $C_{12} = 101.6(11)$, and $C_{44} = 90.0(3)$, with aggregate sound velocities $V_p = 8.90(4)$ km/s and $V_s = 5.03(3)$ km/s and $\rho_0 = 3.534(6)$ g/cm$^3$. The percent difference between our ambient values and those of a modal mixture of the garnet endmembers is: $\Delta K = -8.2(2)%$, $\Delta G = -3.8(1)%$, $\Delta C_{11} = -7.6(4)%$, $\Delta C_{12} = -7(1)%$, $\Delta C_{44} = -3.8(3)%$, $\Delta V_p = -2.0(4)%$, and $\Delta V_s = -0.8(6)%$. Aggregate sound velocities were fit to a third order finite-strain EOS to determine $dK/dP$ and $dG/dP$, as well as the density at high pressure. Our resulting best-fit parameters for the aggregate elastic properties are: $dK/dP = 4.08(3)$, $dG/dP = 1.20(2)$. Compared to pyrope, our pressure derivatives are similar for the bulk and shear moduli, but different for the single-crystal moduli. At ambient conditions, garnets are widely observed to be acoustically isotropic or nearly so. However, we find that the magnitude of the anisotropy factor increases with pressure, from $A = 0.010$ at ambient pressure, to $A = -0.035$ at 14 GPa. Most single-crystal sound velocity measurements on mixed composition garnets have shown little deviation from a linear mixing model. However, a recent static compression study on two eclogitic mixed-composition garnets reports a similarly low $K_0$ as observed from our results. Understanding the contribution of complex garnets to the elasticity of the mantle may require a larger range of compositions to be measured under real mantle $P,T$ conditions.